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Possible use of power LEDs for lighting and communication

Abstract. *Over the past decade rapid development of communication technology happened in the field of optoelectronics. At this time metallic lines are no able to transmit large amount of data such as optical fibers. Practicallyall backbone communication networks are built on optical fibers, whereas it can be expected a their significant role in the last mile networks. As an alternative to last mile networks it could take the so-called free space optical networks (FSO), whether the indoor FSO or outdoor FSO links (point-to-point). The development of power LEDs enables to use these components for lighting the space and together as an optical transmission point in indoor FSO. This article is focused on experimental verification of the possible use of power LEDs for simultaneous wireless communication and lighting of room (spectral and radiation characteristics depending on the OOK modulation).*

Streszczenie. *Ostatnie dziesięciolecia przyniosły, w dziedzinie optoelektroniki, szybki rozwój technologii komunikacyjnych. Oczekiwania współczeności rosną i dzisiejsze łącza metaliczne nie są już w stanie przenieść tak wielkiej ilości danych jak światłowody, przy czym można oczekiwać wzrost ich znaczenia w sieciach ostatniej mili. Jako alternatywę dla sieci ostatniej mili należy przyjąć tzw. optyczne sieci bezwłóknowe (FSO), niezależnie od tego, czy mowa będzie o FSO dla pomieszczeń wewnętrznych czy też o FSO dla łącz zewnętrznych (point-to-point). Rozwój LED dużej mocy umożliwił użycie tych komponentów do oświetlenia danej przestrzeni a jednocześnie jako punktu nadawczego w optycznej sieci bezwłóknowej realizowanej w pomieszczeniach wewnętrznych. Artykuł koncentruje się na eksperymentalnej weryfikacji możliwości jednoczesnego wykorzystania LED dużej mocy do bezwłóknowej komunikacji i oświetlenia danej przestrzeni (charakterystyka widma i promieniowania w zależności od modulacji OOK).* ***(Możliwości użycia LED dużej mocy do oświetlenia i komunikacji).***

Keywords: power LEDs, free space optical networks, spectral characteristics, radiation characteristics, OOK.
Słowa kluczowe: LED dużej mocy, optyczne sieci bezwłóknowe, charakterystyka widma, charakterystyka promieniowania, OOK.

Introduction

Free space optical networks (FSO) can be imaged as an alternative to last mile networks (PON, xDSL, Wi-Fi, etc.). The source of optical radiation could be a laser diodes or LEDs. The first indoor FSO was developed in 1979 [1]. This technology used a spread infrared radiation around the intended area. Currently, it has already been successfully commercialized in several systems for which the infrared spectrum was used. Since 2001, Philips Lumileds company has started to produce power LEDs on the power of 1 W. In time, the technology of power LEDs improved. Early in 2008, the power LEDs, which were able to emit white light with a luminous efficiency of 120lm/W, appeared in the market. The original idea was to use the power LEDs as a saving light source in area, but currently it is undergoing to experimental validation of eventual use for indoor FSO.

Indoor free space optical networks FSO – indirectly oriented systems

In the architecture of directly oriented systems low optical performance can be used, because the optical performance is concentrated in a narrow beam and creates a high power flux density in the optical receiver. Thanks to narrow concentrated beam this architecture is only suitable for connecting point-to-point. In case of an indirectly oriented systems LOS the base station is placed above the intended area (as lighting). To ensure that the system could meet the requirements of multiple mobile users within a relatively large area of coverage, the narrow beam of light has to be replaced by a wide light cone, which defines the optical communication cell (Fig. 1) [2].

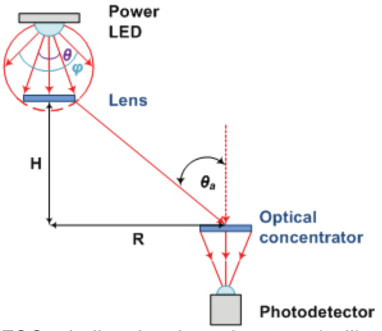

Fig. 1: Indoor FSO – indirectly oriented system (cell)

The optical concentrator is able to receive ambient light to an angle which corresponds to the size of the optical communication cell radius R. The theoretical model is determination is based on theoretical considerations, that the optical radiation radiates lossless through an environment [3]. The relationship between the area A_R, from which the optical concentrator can receive, and the detector area $A_{\det}$ can be described as:

(1) $$A_R \sin^2 \theta_a = A_{\det} n^2 ,$$

where: n – refractive index of optical concentrator.

The optical performance of the photodetector P_{PD} can be determined by equation:

(2) $$P_{PD} = \frac{P_{OS} n^2 A_{\det} \cos\theta_a}{A_{\mathrm{cov}} \sin^2 \theta_a} ,$$

where: P_{OS} – optical power from source of radiation, A_{cov} – area of coverage of optical communication cell, which is determined as:

(3) $$A_{\mathrm{cov}} = \pi H^2 \tan^2 \theta_a .$$

White emitting power LEDs

LEDs generate a white light by use of blue LEDs and luminophore, which is located on the chip surface. White LEDs are the latest and the youngest type of light emitting diodes. A shade of white light is given by a color temperature in Kelvin degrees, because the white light includes almost all wavelengths of visible spectrum of colors.

In practice, so-called yellow luminophore called YAG (Yttrium, Aluminum, and Garnet) is applied as a luminophore, in short $Y_3Al_5O_{12}$. YAG is a colorless, optically isotropic cubic crystal structure. Today it is the primary crystals for garnet lasers, because the technique its cultivation and processing into a rod shapes while maintaining the highest optical quality is managed.

Used luminophor yttrium aluminum garnet is in addition doped by Cerium (a chemical symbol Ce). The resulting yellow luminophore is written in the form of $Y_3Al_5O_{12}$: Ce3

(YAG: Ce). It is implemented into a chip with a help of special method called Lumiramic, which increases dramatically the quality of white light. The photons of blue light are largely absorbed by the luminophore. It then emits light with a lower energy level (longer wavelength). The final spectrum in Fig. 2 is composed by luminescence emitted by the chip, and phosphorescence emitted by an yellow luminophore. The human eye sees the combination of these two wavelengths as a white light.

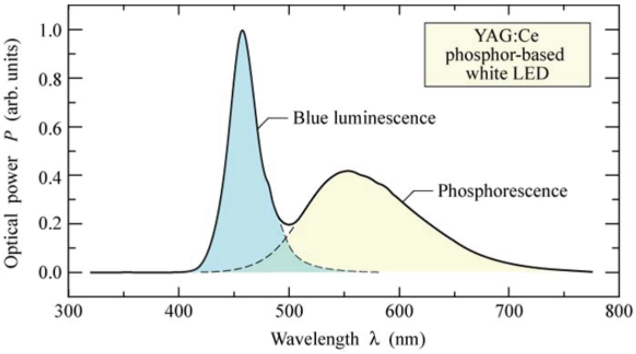

Fig. 2: Emission spectrum of a phosphor-based white LED [4]

The spectral characteristic of white power LEDs can provide a luminous flux Φ [lm], when use a relationship:

$$\Phi = 683\frac{lm}{W}\int_{380nm}^{720nm} p(\lambda)V(\lambda)d\lambda\,, \tag{4}$$

where: $V(\lambda)$ – sensitivity of human eye.

The luminous flux is the optical performance of source of radiation in the spectral region of the human eye. The illuminance [lx] means, that the luminous flux of 1 lm impinges in an area 1m^2, which induces a lightning of 1 lx.

Basic requirements of the light source for the optical communications

The replacement model of LED is shown in fig. 3, which includes parasitic capacitance and inductance. In the forward direction, the cause of the capacity of diode is so-called diffusion capacity C_{dif}, which is presented by redundant charge injected into the PN junction. This capacity can be significantly reduced by increasing the radiative recombination rate (by increasing the density of charges - increasing injection current as well as increasing the rate of nonradiative recombination - an increase of doping in the PN junction). A greater capacity means a narrower bandwidth of LEDs.

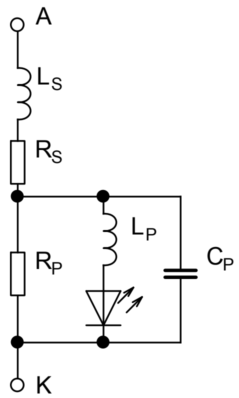

Fig. 3: The replacement model of LED

The other capacitance by LEDs is a barrier capacitance C_{bar}, which arises due to energy barriers of PN junction. This junction separates the positive and negative charge of immobile donors and acceptors, which acts as a plate capacitor. The size of this capacitance varies in depending on the width of a depletion region, that is dependent on the size of the applied voltage between the anode and cathode. The capacity C_{bar} prevails in the reverse direction and can only be reduced by decrease of general area of the chip.

The parallel capacity C_p is already mentioned as diffusion and a barrier capacity. If we use the LEDs at very high frequencies, a small capacity and series resistor can create a RC element with a time constant τ. The RC element behaves as an integrator, which causes deformation of the original signal [5].

The rise edge of pulse is bevelled due to the capacity. Moreover, a shot noises appear in the P/I characteristics, which are affecting the input signal. Therefore, the operating point is preferred in nearly zero. Then the signal to noise ratio is optimal.

The most important requirements of light sources are:

- a sufficient optical power at the appropriate spatial and spectral distribution of luminous flux,
- a possibility of fast modulation,
- a sufficient lifetime,
- a small size and weight.

OOK modulation (On-Off Keying) of power LEDs

An OOK modulation is one of the simplest types of modulation, where a logical value "1" is encoded as light pulse. There are used pulses with a rectangular shape to reduce the complexity of the modulator. A bit rate of one bit is presented as $R_b = 1/T_b$, where T_b denotes the duration of one bit. An important parameter (except BER), which has to be considered in any modulation scheme, is a demand for bandwidth. The bandwidth is estimated as a spectral density of the signal via a Fourier transform using the autocorrelation function. The spectral density of the signal modulated using OOK without correlation at the input has the form [6]:

$$S(f)_{OOK} = \frac{i_S^2}{4R_b}\operatorname{sinc}^2\left(\frac{\pi f}{R_b}\right)\left[1 + R_b\sum_{k=-\infty}^{\infty}\delta(f - kR_b)\right], \tag{5}$$

where: *sinc(x)=sin(x)/x, δ(x)* – Dirac function, i_S – average value of photoelectric current generated in the source of optical radiation, *f* – frequency.

The spectrum of signal is infinite, because the duration of the pulse is finite. A pulse with zero frequency corresponds to the DC component and represents the energy balance. increasing The requirement at the bandwidth increases with the decreasing value of pulse δ. For a value of δ = 0.5 a modulation scheme is usually called as OOK RZ (return to zero) and can double the bandwidth against the above mentioned modulation scheme OOK NRZ (non return to zero).

The OOK NRZ modulation scheme was used in the experimental measurement of the white power LED Luxeon V Star LXHL-5 Watt LW6C. A block diagram of experimental measurement is shown in fig. 4. An internal wiring of transmission block has been designed for use in automotive - communication V2V2I. The estimated transmission rate for transmission of relevant information between vehicles and infrastructure is around 400 kBps [7]. Measurements showed that the bandwidth of power LED (greater than 50 MHz) is large enough to support data transmission in the range of tens MBps [8].

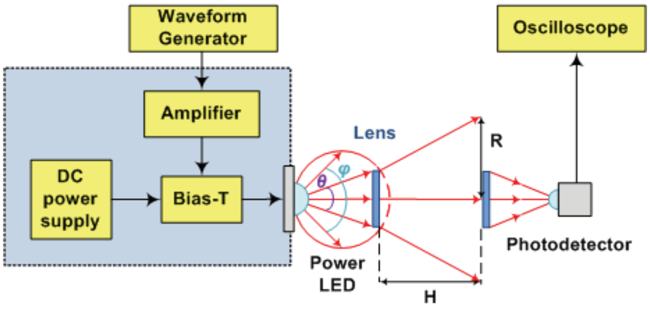

Fig. 4: The block diagram of experimental measurement of cut-off frequency for white power LED Luxeon V star 5 Watt LXHL-LW6C

A distance H was 2 m in the experimental measurement. An operating current of the power LED was set to I_P = 70 mA. This operating current setting causes the generation of light with DC components. Modulated power LED current was given I_D = 700 mA. If this current is set, the power LED gives 100% of its optical power according a datasheet. One half of the maximum optical power determines loss of optical power by 3 dB. When a generator increases the frequency to the loss optical power by 3 dB towards its maximum peak, the corresponding frequency indicates the cut-off frequency, which is important for use in the field of communications. The generator Rohde & Schwarz SMB 100 A and oscilloscope LeCroy WaveRunner 204MXI were used. As a photodetector was used Thorlabs DET10A module with a rise time of 1 ns and working in the wavelength range 200-1100 nm. Selected cut-off frequencies of the modulated currents I_D = 400, 700 mA are shown in fig. 5.

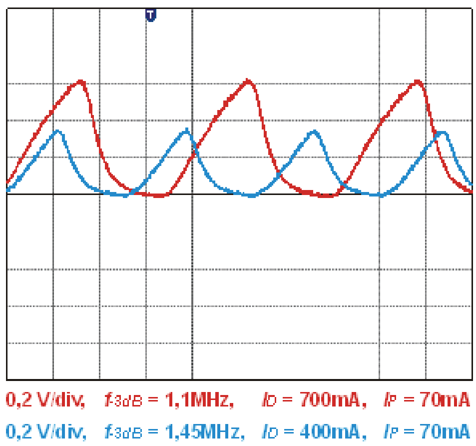

Fig. 5: Measured cut-off frequencies for power LED Luxeon V star 5 Watt LXHL-LW6C

Influence of power LED chip temperature on its spectral characteristics

The same as other sources of optical radiation used for communication purposes (optical fiber and free space systems), it has to be considered thermal stabilization of power LEDs. A change of power LED chip temperature can cause a radical influence on P/I characteristics and spectral characteristics, when power LEDs are used as a light sources in the rooms.

For the experimental measurement of the influence of the power LED chip temperature (Luxeon V Star LXHL-5 Watt LW6C) on the change of the spectral characteristics the oil bath was used in the device Memmert One 7-45. Diagram of the experimental involvement is the fig. 6.

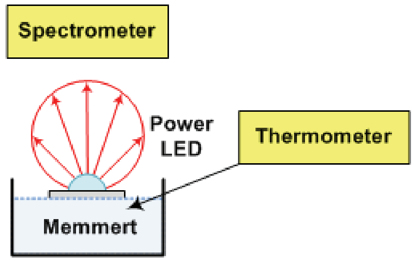

Fig. 6: The block diagram of experimental involving for measurement of influence of the power LED chip temperature (Luxeon V star 5 Watt LXHL-LW6C) on spectral characteristics

The spectrometer Ocean Optics USB4000 was used, which enables to measure spectral characteristics in range form 200 to 1100 nm. The final measured spectral characteristics for modulated current I_D = 400, 700 *mA* is shown in fig. 6, 7.

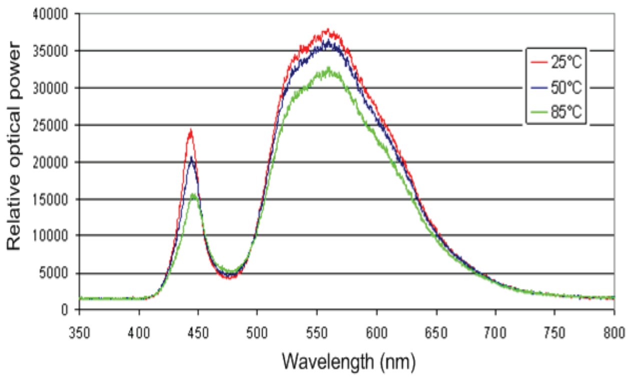

Fig. 6: Influence the power LED chip temperature (Luxeon V star 5 Watt LXHL-LW6C) on spectral characteristics with modulated current I_D = *400 mA*

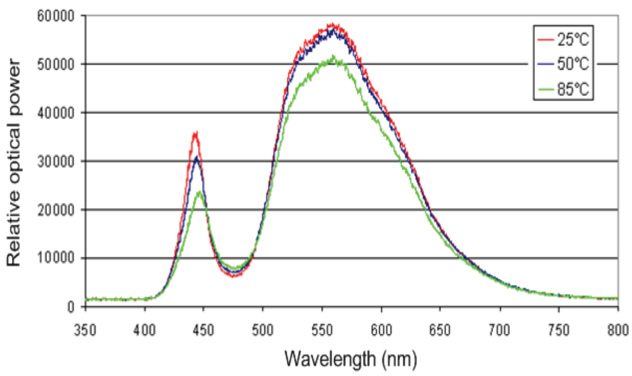

Fig. 7: Influence the power LED chip temperature (Luxeon V star 5 Watt LXHL-LW6C) on spectral characteristics with modulated current I_D = *700 mA*

Conclusion

Power LEDs represent the future and an alternative to conventional lighting elements. Their advantage is the ability to be used for communication purposes. From the perspective of the development of lighting elements they may be used in the automotive industry soon. Due to accidents on European roads, the EU decided to reduce the count of traffic accidents involving fatalities in 2010 to a half, compared to the 2001 state [9]. The result of finding solutions is the introduction of informative-communicative systems on the principle of exchange of information between vehicles and also between vehicles and infrastructure along the road. These systems are called in shortcut V2V2I (Vehicle-to-Vehicle-to-Infrastructure). The recent development of LED technology and adaptive car lighting systems shows benefits of use of alternative communication systems based on free space optics.

However, the experimental measurements shown that is necessary to solve a thermal stabilization. When OOK NRZ modulation scheme is used it can not be achieved large bit rates. To increase the bit rate over 100 Mbps, while using the power LEDs as a source of information is necessary to use other more complex modulation schemes. An example may be a discrete multi-tone modulation (DMT Discrete Multi-Tone Modulation). This allows bit rate 117-182 MBps for a bandwidth of 24 MHz [10]. Then power LEDs could not be used only to illuminate an area, but also for the transmission of information.

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